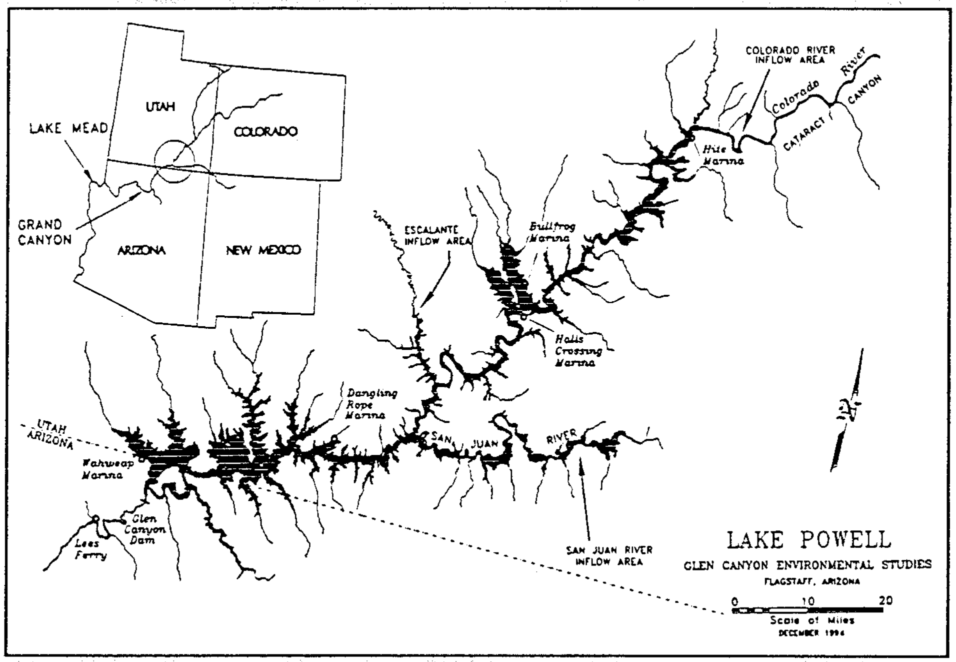
LAKE POWELL

The Future of a Reservoir



At the age of 32, Lake Powell is still a young reservoir. It was created in 1963 when Glen Canyon Dam was closed, drowning the top 140 miles of Glen Canyon and on up into Cataract Canyon; 15 miles of breathtaking Glen Canyon still exist in a quasi-natural state below the dam. Lake Powell is a large reservoir situated in northern Arizona and southern Utah. It has a surface area of 252.2 square miles and approximately 2000 miles of shoreline. It is an incongruous though beautiful sight out upon the high desert, attracting 2.8 million visitors a year. In the summer it's downright chummy. When full, the lake holds 27 million acre feet (MAF) of water. Its mean hydraulic residence time (the time it takes for the inflow to equal the lake's volume) is roughly 2 years. Ninety five percent of its inflow comes from two rivers; the Colorado River (79 percent) and the San Juan River (16 percent); accounting for an average annual inflow of 13.5 MAF.

The lake was constructed as one in a series of storage reservoirs, ensuring that the lower Colorado River basin states (Arizona, California and Nevada) and Mexico were guaranteed delivery of their mandated water allotment— even in times of drought. Only then were the upper basin states (Colorado, Utah, Wyoming, New Mexico and Arizona) free to develop their portion of the Colorado River system's waters.

Lake Powell reached its full pool elevation of 3700 feet above mean sea level in 1980, becoming one of the deepest reservoirs in the world at 525 feet. Climatic fluctuations and downstream obligations result in dramatic fluctuations in the reservoir's level year to year and season to season. Changes of 20 to 50 feet in a year are not uncommon. This fluctuating and rocky shoreline allows little opportunity for the development of riparian areas, and continues to be dominated by exotic species such as tamarisk and russian thistle.

Lake Powell has reached full pool only five times since its filling, and the likelihood for achieving full pool in the future will only decline. Climatic fluctuations aside, there is the further problem of increasing usage of upper basin water. The upper basin states are allotted six MAF each year and are currently using just under 4 MAF. Agricultural and industrial growth is expected to absorb the final 2 MAF per year over the next 70 years. Serious conservation will have to be implemented if Lake Powell water levels are to be maintained in the future.

Limnology of a Reservoir

Stratification or layering of the lake water is a key element to its functioning, and an important consideration for the river below the dam. Reservoirs tend to stratify both horizontally and vertically. Powell has a three-phase longitudinal stratification. It is dominated by riverine influences at its inflow where turbulent muddy waters higher in nutrients are driven by an advective (pushing) current. Downlake there is a transitional zone where light penetration increases as silt settles out and nutrient levels remain high, and these areas are likely to demonstrate the greatest productivity in the form of algal blooms. The deeper parts of the reservoir,

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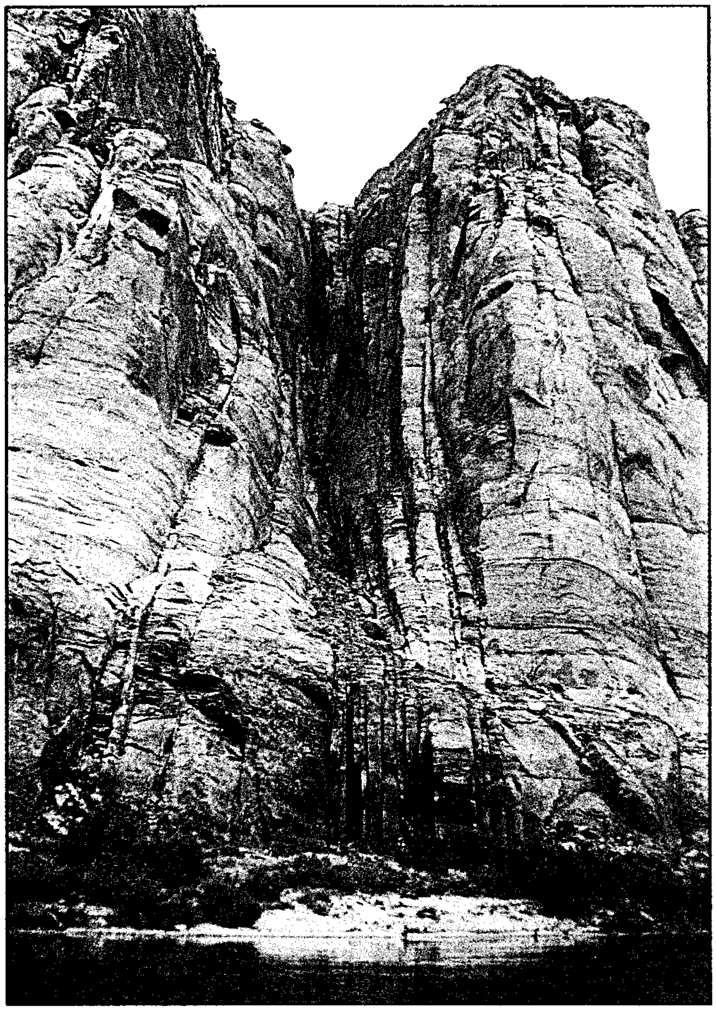
generally the lower two thirds of Lake Powell, exhibit the typical lacustrine or lake-like conditions as seen in figure [isopleth]; vertical stratification becomes established because of temperature and density differences. The epilimnion contains seasonally the warmer surface waters with the greatest biological activity because of light and oxygen availability. A transition zone, the metalimnion, represents a steep gradient to the conditions found at the bottom. Powell can exhibit a thermocline (temperature gradient) and/or a chemocline (chemical gradient) overlying the cold, dark waters of the hypolimnion, where temperatures are consistently 6°C to 8°C (43°F to 46°F), with low oxygen levels and highly saline water forming a stable layer of dense bottom water.

Most temperate reservoirs mix once or twice a year, a process which cycles nutrients trapped at the bottom to the surface—stimulating algae and zooplankton growth which in turn provides food for fish. Temperate lakes typically experience convective circulation during fall cooling and/or spring warming when surface water surpasses the density of the water below. The water then sinks and mixing occurs, furthered by wind activity. This mixing is never complete at Lake Powell because of its great depth and a persistent chemocline. More effective turnover is initiated through the advective currents produced by the river inflows, which vary by season. The spring floods bring muddy, nutrient-rich water which is warm and light enough to skim at or near the surface. By midsummer the flows are even warmer and have enough dissolved salts to become denser than the lake's surface waters, but not as dense as the cold hypolimnion, and so flow between the top and bottom. By winter the river is so cold and dense it flows along the bottom of the lake, providing the only circulation to the deepest waters and preventing oxygen depletion. The action of the penstocks (the ports in the dam leading to the turbines which generate electricity) also produces currents in the lake, but whether they affect several, tens or a hundred miles is as yet unknown. With these patterns in mind we can examine the fate of some of the components making up Lake Powell's water.



SUSAN HUEFTLE

Glen Canyon below dam. Last surviving 15 miles of canyon.

The Biogeochemistry

For the most part, Lake Powell acts as a sink for the various constituents entering

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it. The spring floods deliver the bulk of Lake Powell's sediment load, from 30 to over 100 million tons annually. The muddy water is characteristic of the arid west with its bare rock and sparse vegetation. The sands, silts and most of the clays drop out of suspension upon entering the quiescent lake waters, taking with them nutrients and various ions including toxic metals which adsorb to the particles. These deltas that form in the inflow areas of the Colorado and San Juan Rivers may be 50 to 150 feet thick; thicker following large floods that raise the lake's level.

Sedimentation will eventually limit the useful life of the Lake Powell. As more dams were constructed in the Colorado River watershed, the sediment load was distributed across each reservoir. Lake Mead, built in the 1930's below Grand Canyon, was silting in so fast its life expectancy was only about 300 years. The construction of Glen Canyon Dam reduced the sediment load to Lake Mead by 90 to 95percent, extending Mead's life to 500 years. Currently, Lake Powell's life expectancy is between 500 and 700 years, and there is probably little that can be done to reduce the sediment load to Lake Powell. The days of significant dam construction are likely over.

The physical process of sedimentation has had a major impact on the chemical composition of Lake Powell. The limiting nutrient in most lakes is phosphorus, and over 90percent of the phosphorus coming into Lake Powell is adsorbed to the sediments that form the deltas. Phosphorus levels at the dam are often below detectible limits, seriously reducing the nutrients availability to the river

SUSAN HUEFILE

Lake Powell above San Juan River confluence.

ecosystem below the dam. Nitrogen, also important for primary production (algal growth), is also retained in the reservoir but to a lesser extent. These nutrients appear to be locked up more or less permanently in the deltaic sediments, and resuspension of the delta when lake levels drop does not appear to produce a sustained increase in available nutrients.

The retention of two other minerals, silica and calcite, are related to algal activity in the lake. Diatoms are the most common type of algae at Lake Powell, especially at the lower end of the lake. Their cells are composed mostly of silica which they extract from the water. As they die and settle out, they remove silica from the water.

In a less direct reaction, calcite or calcium carbonate, $CaCO_3$, is removed from lake water. During an algal bloom, the algae can raise the pH of the water by consuming carbon dioxide. Calcium dissolved in the water reaches a critical saturation point as the water becomes more basic and will precipitate out. This is demonstrated both in the white bathtub ring seen at the high water line of the reservoir and dramatically in mid to late summer when Powell's waters turn a luminescent turquoise-blue as the light refracts off the tiny crystals in the water. Thus Lake Powell reduces overall salinity levels downstream by retaining $CaCO_3$.

Salinity levels have become an important issue in the arid west. Reservoirs in arid regions experience high evaporation levels. In Powell's case, up to six feet of water per year are evaporated while precipitation is only about six inches per year. This condition results in an increase in salt concentrations in the reservoir. This is problematic not only because of adverse effects on irrigated crops, but also because the U.S. has a legal obligation to deliver Colorado River water to Mexico that is of acceptable quality. A de-salinization plant built in Yuma, Arizona has not yet proven feasible in reducing salt levels, and other management options are being explored, such as retirement of highly saline agricultural lands or conservation.

Lake Powell derives most of its salinity from geologic strata in its watershed, as well as from irrigation return flows in the upper basin. Although its waters are still within range of acceptable salinity levels, Powell itself is not used for irrigation. But with each of the eight dams between Powell and Mexico acting as evaporation pans, the water becomes progressively saline. The penstocks or outlets in Glen Canyon Dam release upper hypolimnetic water which tends to be higher in many of the salt ions which are most harmful to crops, including sodium, sulfate, and chloride.

Heavy metal concentrations in Lake Powell are also being studied. As with salinity, they are derived from geologic formations in the watershed, as well as from mining and industrial discharges in the upper basin. Many of these elements are also adsorbed to the sediments deposited in the lake bottom, but mercury, selenium and lead are of primary concern because of their toxicity in small doses. Research is continuing to determine water concentrations and levels of bioaccumulation occurring in the fish and fowl.

Lake Powell's effects on Grand Canyon

The limnology of Lake Powell and dam operations control the Colorado River below Glen Canyon Dam. With the passage of the Grand Canyon Protection Act in 1992 and the recently completed EIS, the need to understand this reservoir that has altered the ecosystem in Grand Canyon is being recognized and accelerated. It was out of this need that Glen Canyon Environmental Studies arose from the Bureau of Reclamation, and has led the way in a long-term monitoring program for Lake Powell.

The water released through the penstocks determines the quality and quantity of flows below the dam. The location of the penstocks, generally 60 m (200 feet) beneath the lake surface coincides with the lower thermocline or hypolimnion, depending on the reservoir level. As mentioned previously, these waters are very cold year round—usually 8°C to 10°C (46°F to 50°F) but occasionally

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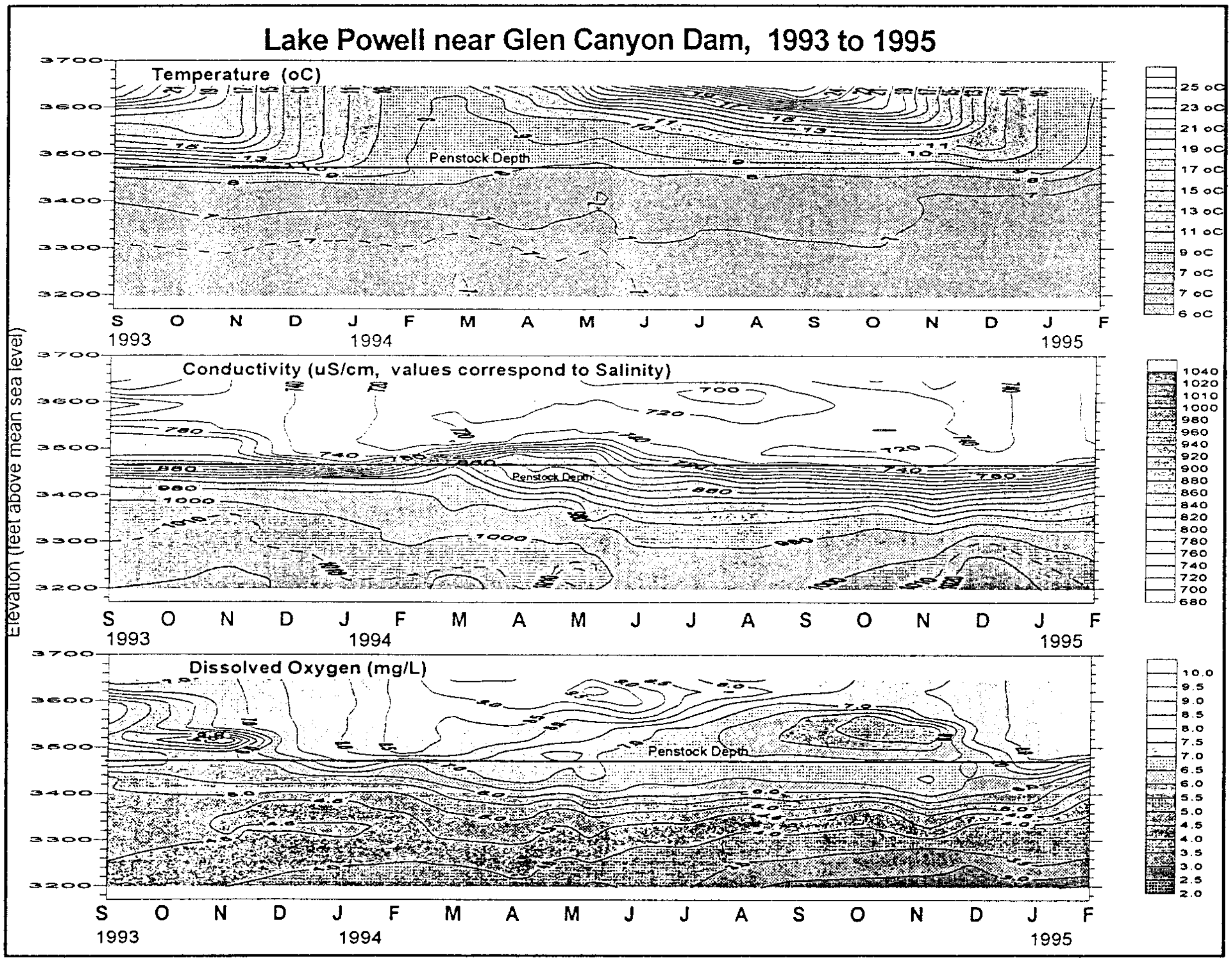
as high as 12°C (54°F). The water is clear and low in oxygen, with somewhat higher salinity and nutrient levels than found at the surface. In general, the effect has been to average out the yearly variability of the river. Organisms (and habitats) that were adapted to pre-dam conditions of seasonally warm, turbid, annually variable flows may not be able to exist, survive or compete in perennially cold, often clear flows.

At public insistence, federal NEPA regulations have required an evaluation and mitigation of problems stemming from the lake and dam operations above Grand Canyon. Interim flows from Glen Canyon Dam have already moderated traditional dam discharge practices that often led to river level fluctuations of 5 to 10 feet twice a day. Controlled experimental floods are also planned in the next 2 years in an effort to build up eroding beach habitat. These may be contested by those who fish the blue-ribbon trout fishery just below the dam. They fear the non-native fish will be diminished by the floods, though the flood levels will not begin to approach those of pre-dam spring runoff. Representatives for water and electrical users have also expressed concerns over the legal right to conduct the experiment.

The construction of a selective withdrawal system (SWS) on the dam is also being considered that would alter the discharge levels from the lake. Drawing water from the upper thermocline or epilimnion in the late spring to early summer would increase downstream temperatures. The objective of the SWS is to enable the endangered humpback chub, one of the remaining native fish species in Grand Canyon, to spawn and survive in the mainstem of the river. Impacts to the reservoir could include an alteration of the heat budget-- by thinning the epilimnion, mixing could increase and evaporation could decrease; thus, there is a potential for overall cooling to the reservoir. Lower lake temp-eratures could impact the non-native threadfin shad, the main forage fish for stripped bass in Lake Powell. Selective withdrawal could cause nutrients and salinity to build up in the hypolimnion; whereas heavy metals at the surface from the nearby coal burning power plant and boat exhaust by-products could be more easily transported to the ecosystem downstream. The biotic community in the epilimnion could also be altered—algae, zooplankton and fish could be entrained in the discharge. And it is unclear whether in-stream warming in Grand Canyon would also benefit competitors of the humpback chub.



Vertical stratification of temperature, salinity (conductivity) and dissolved oxygen in Lake Powell from September, 1993 to February, 1995. Note seasonal mixing trends and the persistant cold, dense, saline layer at and below the penstock depth.

Lake Powell will continue to act as a physical and chemical filter for the Colorado River. Since the reservoir itself is a still-evolving, artificial system, it can be difficult to know which changes are beneficial overall and which are not. Like petroleum, Glen Canyon was a non-renewable resource. We have the obligation to treat it with respect and make the most of the beautiful lake that came from Glen Canyon's sacrifice. We would do well to overcome mistakes of the past and consider the entire ecosystem of the Colorado River as a complex and interrelated whole.

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Lake Powell in Cha Canyon Bay.

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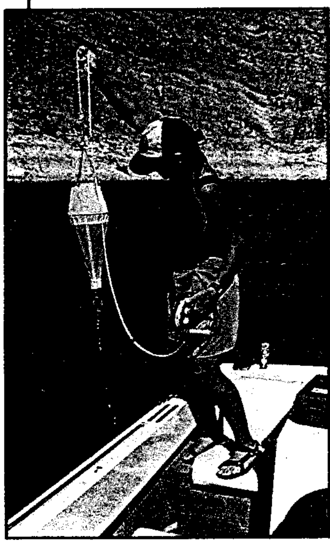

M. HORN

Susan Hueftle taking zoop sample on Lake Mead.

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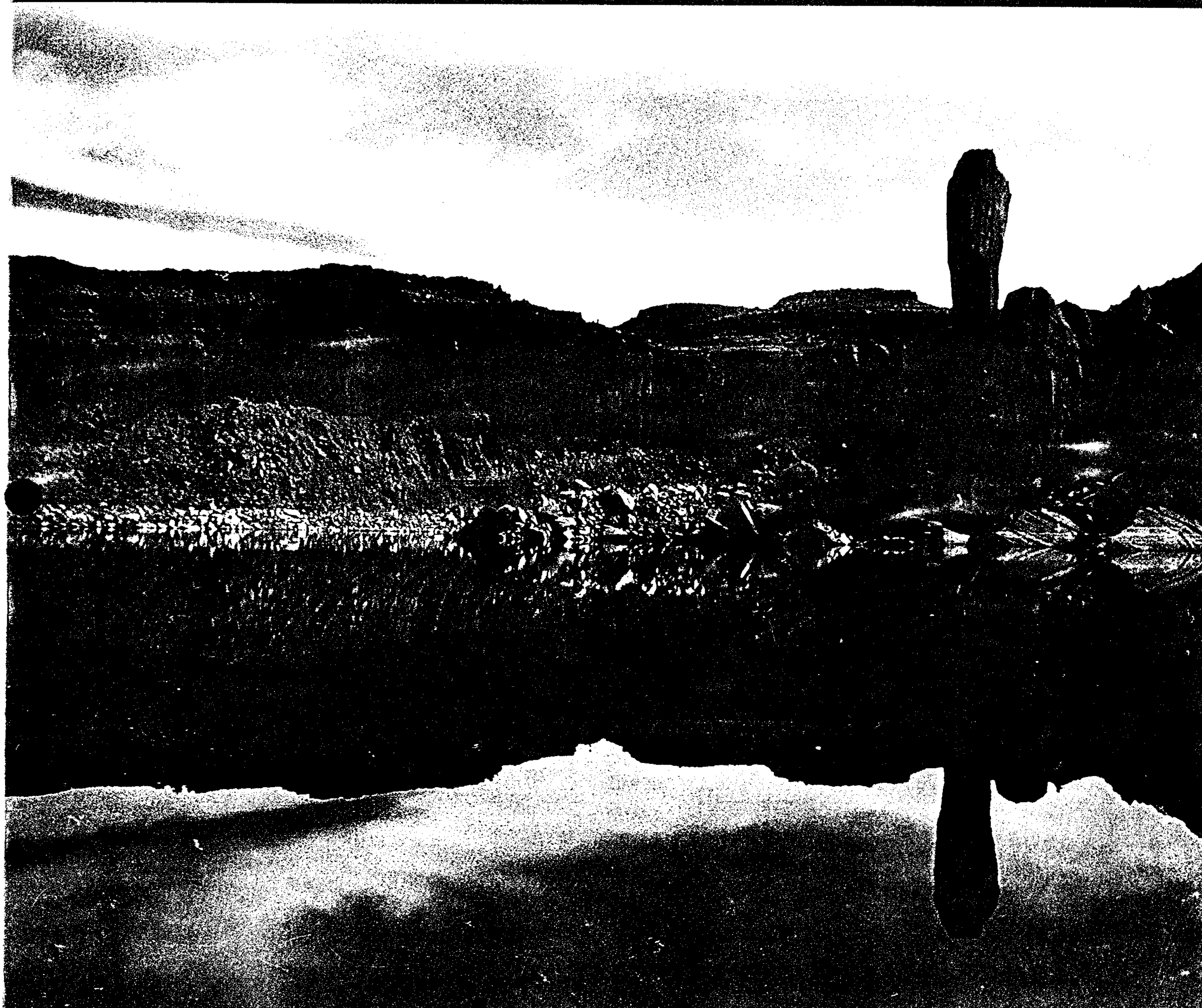
a publication of

Vol. 15, No. 1 | North American Lake Management Society | April 1995



RESERVOIRS

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